Safety Study Plan

General Aviation Air Bag Effectiveness Study

Introduction

In the early 1970s, as manufacturers were examining the effectiveness of air bags in automobiles, air bag technology was also being explored for use in preventing injury in general aviation (GA) aircraft. The results of this early research showed a benefit of air bags in reducing head injuries but also found that shoulder harness use would provide a similar benefit. In the mid 1980s, the Federal Aviation Administration (FAA) and the National Transportation Safety Board focused on increasing the use of shoulder harnesses in general aviation. By the 1990s, manufacturers were required to install shoulder harnesses and pilots were required to use them during takeoffs and landings.

In 1985, the Safety Board examined harness use by pilots in 535 accidents occurring in 1982.[1] The Board found that shoulder harnesses were available for only 50 percent of the 902 front seat occupants in these accidents and that only 40 percent of the pilots used the shoulder harnesses that were available. Data from the Safety Board's Aviation Accident Database revealed that in 2002, the proportion of pilots who used shoulder harnesses had increased to nearly 80 percent: 1,193 used their shoulder harnesses while 324 did not.

This increase in shoulder harness use represents a substantial increase in safety for pilots in GA aircraft. However, research on the survivability of GA accidents has shown that pilots continue to die in potentially survivable accidents.[2] Li and Baker[3] examined the injuries resulting in fatalities in GA accidents. Although most fatalities were the result of multiple injuries, 22 percent of the fatalities resulted solely from head injuries and 12 percent solely from thoracic injuries. The researchers found that air bags would be effective in reducing head and thoracic injury severity affecting the survivability of one-third of the fatalities in GA accidents.

In 2001, air bags were introduced to commercial aircraft to protect passengers seated in bulkhead rows.[4] In the same year, air bags were introduced in military rotorcraft.[5] In 2004, the

[1] National Transportation Safety Board, *General Aviation Crashworthiness Project Phase Two—Impact Severity and Potential Injury Prevention in GA Accidents*, Safety Report NTSB/SR85/01 (adopted March 15, 1985).

[2] For an accident to be deemed survivable, the forces transmitted to occupants through the seat and restraint system cannot exceed the limits of human tolerance to abrupt accelerations, and the structure in the occupants' immediate environment must remain substantially intact to the extent that a livable volume is provided for the occupants throughout the crash.

[3] G. Li and S. Baker, Injury Patterns in Aviation-Related Fatalities: Implications for Preventive Strategies," *American Journal of Forensic Medicine & Pathology* 18(3):265-270, September 1997.

[4] Statistics on air bag installation in commercial and general aviation from Amsafe website (www.amsafe.com). Amsafe designs and supplies shoulder harness air bags.

[5] "Air Bags for Aircraft," *Popular Mechanics*, January 1, 1997.

first air bags were certificated for pilot and co-pilot seats on a GA aircraft, an AMD Alarus. In 2005, other manufacturers, such as Mooney, Cessna, and Cirrus, began offering air bags as standard equipment on their GA aircraft. In 2006, approximately 60 percent of newly manufactured GA aircraft will be equipped with air bags. Table 1 lists GA aircraft that are being manufactured with air bags as standard equipment.

Table 1. Aircraft with air bags installed in the cockpit/cabin.

Aircraft	Positions
Adam A500	pilot and co-pilot seats
Adam A700	pilot and co-pilot seats
Aviat Husky A1	pilot and co-pilot seats
Aviat Husky A1A	pilot and co-pilot seats
Aviat Husky A1B	pilot and co-pilot seats
Cessna 172 Skyhawk	pilot, co-pilot, and rear bench seats
Cessna 172S Skyhawk	pilot, co-pilot, and rear bench seats
Cessna 182 Skylane	pilot, co-pilot, and rear bench seats
Cessna 182 Turbo Skylane	pilot, co-pilot, and rear bench seats
Cessna 206 Stationair	pilot, co-pilot, middle, and rear bench seats
Cessna 206T Turbo Stationair	pilot, co-pilot, middle, and rear bench seats
Cirrus SRV-G2	pilot and co-pilot seats
Cirrus SR20-G2	pilot and co-pilot seats
Cirrus SR20-GTS	pilot and co-pilot seats
Cirrus SR22-G2	pilot and co-pilot seats
Cirrus SR22-GTS	pilot and co-pilot seats
Four Winds FX-210	pilot, co-pilot, and rear seats
Four Winds FX-250T	pilot, co-pilot, and rear seats
Gippsland GA-8 Airvan	pilot, co-pilot, and rear seats
Lancair International IV/IVP & ES	pilot and co-pilot seats
Mooney Ovation	pilot, co-pilot, and rear seats
Mooney Ovation2 DX	pilot, co-pilot, and rear seats
Mooney Ovation2 GX	pilot, co-pilot, and rear seats
Mooney Bravo DX	pilot, co-pilot, and rear seats
Mooney Bravo GX	pilot, co-pilot, and rear seats
Tiger AG-5B	pilot, co-pilot, and rear seats
Zenair Alarus CH 2000	pilot and co-pilot seats

The design of the air bags being introduced into GA cockpits differs from air bags currently installed on automobiles. In automobiles, the air bag is installed in the dash or steering wheel and deploys towards the driver/passenger. The GA air bag is installed in the seat belt/shoulder harness and deploys outward from the pilot or occupant. Figure 1 shows an illustration of a GA air bag-equipped seat belt/harness. The seat belt/harness system contains attachment points that are identical to belt systems without air bags. As such, little design change has been necessary to equip GA aircraft with these air bags.

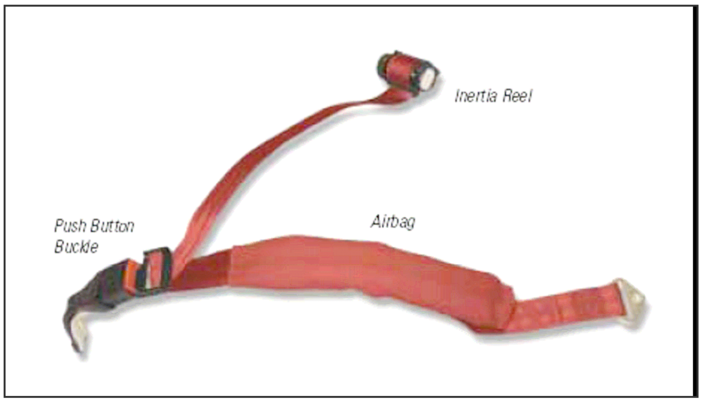

Figure 1. Seat belt/harness air bag system developed by Amsafe. The air bag is contained in the lap portion of the belt. The buckle for the belt is on the side as in automobiles.

The sensors used to detect a crash also differ between automobiles and GA aircraft. The crash sensor used to fire automobile air bags is an accelerometer on a small, integrated circuit chip. The mechanical element in the sensor moves in response to rapid deceleration, and this motion causes a change in capacitance, which is detected by the electronics on the chip, which then sends a signal to the automotive air bag control module. The crash sensor used in GA aircraft is a larger mechanical sensor (ball and spring) that closes a circuit when the aircraft decelerates rapidly, thereby firing the air bag. In addition, automobile air bag control modules store data on vehicle speed, engine speed, and deceleration over time, but GA control modules do not store any data.

The installation of air bags in GA aircraft should, based upon manufacturer tests, significantly reduce head injuries resulting from accidents. Studies using sled tests show a reduction in head injuries with the use of air bags in GA aircraft.[6] Although these data indicate that air bags would increase survivability, no accidents have occurred in aircraft equipped with air bags, so accident data are unavailable to corroborate these findings. Similarly, data are not available to illustrate the unintended consequences of air bag deployment, such as inadvertent deployments or air bag-induced injuries, which Safety Board experience with automobile air bags has shown may occur.

---

[6] L. Roemke, "The Inflatabelt Occupant Restraint System," in *Proceedings of the Technical Cooperative Program Workshop: Inflatable Restraints in Aviation* (2000).

Federal Regulations

Occupant protection for GA fixed wing aircraft is regulated under Title 14 *Code of Federal Regulations* Part 23 and Part 91. Part 23 contains requirements for aircraft and Part 91 contains requirements for those who operate GA aircraft. Although no Federal regulations govern the use of air bags in GA aircraft, Part 23.561 states that "the airplane, although it may be damaged in emergency landing conditions, must be designed … to protect each occupant under those conditions." The section goes on to define the loads under which the aircraft should provide protection to the occupant. Part 23.562 outlines two dynamic tests that manufacturers must use to evaluate the crashworthiness of their aircraft design and to determine that the design meets the regulatory requirements. Part 23.781 regulates the design of seats, berths, litters, safety belts, and shoulder harnesses. Finally, Part 23.2 requires the installation of shoulder harnesses for all GA aircraft manufactured after December 12, 1986.

Previous Safety Board Research and Recommendations

The Safety Board's first study of GA crashworthiness, adopted in 1972, examined the pilot's role in reducing the impact forces of a planned emergency landing.[7] This study provided pilots with strategies to consider when performing an emergency landing to reduce the potential for serious injury or fatality. The primary guideline attempted to decrease deceleration forces by considering the type of flight and terrain characteristics.

In the early 1980s, the Safety Board began a systematic evaluation of crashworthiness of GA aircraft. The first report, adopted in 1980, examined the status of crashworthiness of GA aircraft.[8] This safety report documented past accidents, regulatory developments, and crashworthiness research activities to develop recommendations to improve GA aircraft crashworthiness. As a result of the report, the Board issued seven recommendations calling on the FAA to require that shoulder harnesses be installed, to extend occupant protection provisions of Part 23 to incorporate standards to delethalize the cabin (for example, by removing sharp objects from instrument panels) and to require dynamic testing of occupant protection systems. A second study adopted in 1980 examined postcrash fires for GA aircraft.[9] This study found that the majority of occupants in accidents with postcrash fires were fatally injured. The study resulted in six recommendations to the FAA to improve the crashworthiness of fuel systems in GA aircraft and to examine other efforts that could lead to a reduction in postcrash fires.

In 1983, the Safety Board began a 3-year study examining GA aircraft crashworthiness. Phase one of the study identified and described a methodology for analyzing the crashworthiness

---

[7] National Transportation Safety Board, *Emergency Landing Techniques in Small General Aviation Fixed Wing Aircraft,* NTSB/AAS-72/03 (adopted April 5, 1972).

[8] National Transportation Safety Board, *The Status of General Aviation Aircraft Crashworthiness,* Safety Report NTSB/SR-80/02 (adopted December 17, 1980).

[9] National Transportation Safety Board, *General Aviation Accidents: Postcrash Fires and How to Prevent or Control Them,* NTSB/AAS-80/02 (adopted August 28, 1980).

of a GA aircraft during a Board investigation.[10] Phase two of the study, adopted in 1985, examined 535 accidents involving 1,268 occupants.[11] The Board found that a 20-percent reduction in fatalities would have been possible if all occupants had worn the shoulder harnesses that were available. Further, the Board was able to define a survivable envelope for airplane crashes of 45 knots with impact at 90 degrees, 60 knots with impact at 45 degrees, and 75 knots with impact at 0 degrees.

The final phase of the Safety Board's crashworthiness study examined survivable accidents in which occupants died or were seriously injured to identify improvements needed for GA aircraft crashworthiness.[12] As a result of this study, the Board issued four recommendations to the FAA asking for increased performance standards for occupant protection systems and dynamic testing of seat restraint systems, a requirement for shoulder harness use for all takeoffs and landings, an advisory circular on small aircraft occupant protection, and advisory directives to address component failures identified in the study.

Overall, the Safety Board has issued about 25 recommendations on survivability in GA aircraft, calling for the installation, testing, and use of safety harnesses in GA aircraft. In addition, the Board has issued seven general recommendations calling for improved survivability in GA aircraft through better performance testing and cabin delethalization. The Board has not issued any recommendations on air bags in aviation.

Purpose

The purpose of the proposed exploratory study is to examine accidents involving air bag-equipped GA aircraft to better understand the effects of air bag deployment in actual accident conditions. In addition to collecting air bag information to evaluate this new technology, the study will also develop procedures for future investigations. Further, by examining the first generation of aviation air bags, the Safety Board will be able to identify possible unintended consequences that may result from the introduction of air bags and may be able to identify cases in which air bags were particularly effective at reducing injury.

Study Methods

To collect data for this study, staff from the Safety Studies and Statistical Analysis Division (RE-10), the Vehicle Recorders Division, (RE-40), the Vehicle Performance Division (RE-60), and the Aviation Survival Factors Division (AS-60), as well as the Board's Medical Officer, will develop a supplemental data collection procedure for use during accident investigations involving air bag-equipped GA aircraft. The procedure will include crashes

---

[10] National Transportation Safety Board, General *Aviation Crashworthiness Project, Phase One,* Safety Report NTSB/ SR-83/01 (adopted June 27, 1983).
[11] National Transportation Safety Board, *General Aviation Crashworthiness Project Phase Two—Impact Severity and Potential Injury Prevention in GA Accidents*, Safety Report NTSB/SR-85/01, (adopted March 15, 1985).
[12] National Transportation Safety Board, *General Aviation Crashworthiness Project Phase III—Acceleration Loads and Velocity Changes of Survivable General Aviation Accidents,* Safety Report NTSB/SR-85/02, (adopted September 4, 1985).

involving air bag-equipped GA aircraft whether the air bag deploys or not. Documentation will focus on factors contributing to the crash severity, including the crash site, aircraft velocity, aircraft deceleration, aircraft damage, intrusion into the cockpit, restraint usage, impact marks, and occupant injury patterns. A similar data collection method was used in the Board's investigations of GA aircraft crashworthiness in the early 1980s.

The study will also document the injuries sustained by occupants in the study accidents. This information will come from survivor interviews conducted by AS-60 and RE-10 study personnel. In those cases where interviews cannot be obtained, staff will request medical documentation of the injuries sustained in the crash, including medical records, autopsies, and photographs, which will be reviewed by the Safety Board's Medical Officer to evaluate the role of the air bag in mitigating or causing an injury.

After examining the accident force and air bag deployment data from 10 to 20 accidents involving air bag-equipped aircraft, staff will determine if further research is needed to evaluate this technology, or if conclusions may be made about the efficacy of air bags in GA aircraft.

If the results of the initial air bag investigations require a more detailed evaluation of air bag deployment mechanics, staff from RE-60 will examine the accident data to determine the value of evaluating the effectiveness of air bags in GA aircraft by simulating crashes with and without air bags installed. The simulations would be conducted using the Mathematical Dynamic Modeling (MADYMO) software tool, which has been used to validate the potential benefit of GA air bags using general aviation crash forces but not with forces collected from accident data.[13] RE-60 staff will work with GA air bag manufacturers to identify information requirements necessary to efficiently model air bag deployment. In addition, RE-60 staff will work with the FAA's Civil Aeromedical Institute occupant protection researchers regarding sled testing performed with air bags.

Significance of the Study

To date, no air bags have deployed in GA accidents and the only evaluation of air bags in aviation has taken place in controlled settings. Further, the effect of inadvertent deployments of aviation air bags has been examined only in simulator studies involving military helicopters using different air bag deployment mechanics. The proposed study will be the first to look at deployments in actual crashes. The Safety Board's mandate to investigate all aviation accidents places the Board in the unique position of acquiring information about all air bag-equipped aircraft in GA accidents. As a result of the study, the Board could make recommendations on improvements to air bags, including those to offset the unintended consequences of the air bags. Conversely, the Board may find that GA air bags are very effective and recommend a wider installation in general aviation, such as retrofitting existing aircraft.

---

[13] W. Rockwell, "Design of Inflatable Restraints Using MADYMO," in *Proceedings of the Technical Cooperative Program Workshop: Inflatable Restraints in Aviation* (2000).

Time Requirement

It is anticipated that the development of a supplemental accident investigation form to accommodate the air bag information will take approximately 3 to 4 months. It is difficult to estimate the timeframe for data collection due to the relatively small number of aircraft currently equipped with air bags. In 2006, there will be approximately 215,000 GA aircraft registered in the U.S. with about 3,580 of those being newly manufactured aircraft. Because only 60 percent of those newly manufactured aircraft are equipped with air bags, only about 1 in 100 aircraft in the GA fleet will be air bag equipped. As such, the opportunities to investigate accidents involving air bag-equipped aircraft will be infrequent. Staff plans to collect data from 10 to 20 accidents involving air bag-equipped aircraft detailing accident forces, occupant injury, occupant kinematics, and air bag deployments. After collecting these data, staff will determine if further research is needed to evaluate this technology, or if conclusions may be made about the efficacy of air bags in GA aircraft based on existing data. Data collection for the study is estimated to take 36 months to complete.

Staff Resources

Staff from the Office of Research and Engineering's Safety Studies and Statistical Analysis Division (RE-10) and the Office of Aviation Safety's Survival Factors Division (AS-60) will conduct the general aviation air bag effectiveness study. Study co-managers are Robert Molloy, RE-10 (x6516), and Nora Marshall, AS-60 (x6364). RE-40 and RE-60 staff, and the Safety Board's Medical Officer, will provide support for the study.